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The relationship between Mini-Mental State Examination score, preferred stimulation rate, and speech perception score for adult cochlear implant users

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THE RELATIONSHIP BETWEEN MINI-MENTAL STATE EXAMINATION SCORE, PREFERRED STIMULATION RATE, AND SPEECH PERCEPTION SCORE FOR ADULT COCHLEAR IMPLANT USERS

by

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Abstract: The purpose of the current study was to investigate the relationship between Mini-Mental State Examination (MMSE) score, a measure of cognitive function, and stimulation rate for older adult cochlear implant users. This study also assessed performance as a function of stimulation rate and MMSE score.

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LIST OF ABBREVIATIONS

MMSE: Mini-Mental State Examination

HINT: Hearing in Noise Test

FDA: Food and Drug Administration

HIPAA: Health Insurance Portability and Accountability Act

IRB: Institutional Review Board

ANSD: Auditory Neuropathy Spectrum Disorder

ANOVA: Analysis of Variance

INTRODUCTION AND LITERATURE REVIEW

Americans are experiencing increasingly longer life expectancies now than those twenty-five years ago. With increase in age comes an increase in a number of sensory impairments, one of which is hearing loss (Dillon, Gu, Hoffman & Ko, 2010). The most common sensory impairments seen in the older adult population include vision impairment, balance impairment, neuropathy, and hearing impairment. In fact, according to Dillon, Gu, Hoffman and Ko (2010), one in every four Americans over the age of seventy experiences hearing impairment. Further, thirty percent of American adults between sixty-five and seventy-four years of age and forty-seven percent of adults seventy-five years of age or older reportedly experience hearing loss (NIH Senior Health, 2012; NIDCD, 2013; Agrawal, Platz, & Niparko, 2008). Statistics like these become alarming when the projected growth of this population is considered.

The Federal Interagency Forum on Aging (2010) stated that in 2010, 40 million people age 65 and older were living in the United States, which accounted for thirteen percent of the population. While this alone is a staggering statistic given what we know about sensory impairment in older adults, it is crucial to understand the projected growth in this population facing healthcare professionals and governmental agencies in the coming decades. As compared with the 2010 statistics, a 2013 U.S. Census determined that the percentage of the population over the age of 65 had increased to 14.1%, which equates to over 44.5 million people. This percentage is expected to reach nearly 20% by 2030, as members of the "baby boomer" generation enter the leagues of the older population. While the absolute number of individuals over the age of 65 will continue to increase beyond 2030, the proportion is expected to stabilize (U.S. Census Bureau, 2014; Federal Interagency Forum on Aging, 2010). Given what we know about the occurrence and prevalence of sensory impairment in the older adult population it stands to reason that hearing healthcare's ability to adequately and appropriately serve this subset of the population will be paramount.

Another concern that has drawn a large amount of recent public attention with regard to the older adult population is dementia, and more specifically, Alzheimer's disease. In the most general sense, dementia is a decline in mental ability that interferes with daily life (Alzheimer's Association, 2015). Alzheimer's disease is the most common type of dementia, accounting for approximately seventy percent of all cases. A 2007 study by the National Institutes of Health (NIH) suggests that approximately one in seven Americans age seventy-one and older has some form of dementia; this percentage equates to approximately 2.4 million people. One study suggests that if the current rate continues, an estimated 13.8 million Americans will be affected by Alzheimer's disease by 2050, nearly doubling or tripling in some states (Hebert, Wueve, Scherr, & Evans, 2013; Wueve, Hebert, Scherr, & Evans, 2015). One test that can be utilized by physicians to assess memory and other cognitive functions in the clinic is the Mini-Mental State Examination (MMSE). Because of the nature by which it is administered, MMSE scores can be affected by a number of factors including, but not limited to, cognitive status, hearing sensitivity, learning disability, and native language. However, it still serves as a viable clinical test by which cognitive function can be assessed and serially monitored.

As we see an increasingly larger number of individuals manage the difficulties hearing loss oftentimes involves, audiologists and researchers continue to advance and perfect technologies available to patients for assistance. For patients with hearing loss severe enough to meet specific guidelines set forth by the Food and Drug Administration (FDA), a cochlear implant is one such option. Cochlear implants are intricate electronic medical devices that, contrary to a hearing aid which simply amplifies incoming sound, replace the function of the damaged inner ear (Mayo Clinic, 2015; Cochlear Corporation, 2015; Food and Drug Administration, 2014b). The inner ear contains the cochlea, a snail-shaped bony structure that houses the sensory organ for hearing. Simplistically, the inner ear is responsible for receiving incoming stimuli from the environment, which results in an auditory nerve impulse sending a signal to the brain for processing. Damage resulting from excessive noise exposure, age-related changes, or any number of other pathologies may affect the functionality of this sensory organ, resulting in a hearing loss. Cochlear implants aim to compensate for this damage by providing electrical stimulation directly to the auditory nerve, bypassing any damage within the inner ear structures. A sound processor, typically worn on the ear, collects sound from the environment and transmits it to the internal component through the coil worn on the head. The internal component converts the signal into electrical impulses, which are sent to the array placed in the cochlea to stimulate the auditory nerve. The auditory nerve sends the impulses to the brain to be processed and interpreted (Niparko, 2009).

Guidelines set forth by the FDA outline audiometric requirements for cochlear implant candidacy for adults and pediatric patients separately. Adult guidelines require a moderate to profound sensorineural hearing loss bilaterally with limited benefit obtained from traditional amplification. Limited benefit is defined as pre-operative sentence recognition scores of less than or equal to 50% in the ear to be implanted, and less than or equal to 60% in the best aided condition (Cochlear Corporation, 2015). Guidelines for cochlear implantation candidacy set forth by Medicare, the federal health insurance program for people who are 65 years of age or older, vary from those set forth by the FDA. Similar to those of the FDA, Medicare requires diagnosis of a bilateral moderate-to-profound sensorineural hearing impairment with limited benefit from appropriately fit hearing aids and no surgical contraindications. However, under Medicare guidelines, limited benefit from appropriate amplification is defined as scores less than or equal to 40% correct in the best aided listening condition. Medicare also specifies “the cognitive ability to use auditory clues and a willingness to undergo an extended program of rehabilitation” within its set of eligibility criteria (Centers for Medicare & Medicaid Services, 2014). This specification further highlights the usefulness and relevance of neuropsychological examinations prior to, and periodically throughout, the cochlear implantation journey.

A study by Gifford, Dorman, Shallop and Sydlowski (2010) supported a large-scale reassessment of candidacy criteria, stating that significantly more hearing impaired adults may benefit from cochlear implantation than candidacy criteria currently allowed. This recommendation stemmed from the work of several other researchers, validating the use the electric-acoustic stimulation. In 2014, combined electric-acoustic stimulation cochlear implants, also known as hybrid technology, were approved by the FDA, thereby expanding cochlear implant candidacy criteria (Food and Drug Administration, 2014a; Gantz, Turner & Gfeller, 2006; Gantz & Turner, 2004). Hybrid technology was developed for patients with normal low frequency hearing, which previously would have prevented them from receiving a cochlear implant. With hybrid technology, low frequency hearing is preserved and stimulated using acoustic stimulation, while electric stimulation is utilized to stimulate the impaired high frequency regions. While not currently FDA approved, research by Firszt, Holden, Reeder, Cowdrey, and King (2012) explored the effectiveness of cochlear implantation for asymmetrical, or unilateral, hearing loss. The work of these researchers demonstrates the potential cochlear implantation holds in terms of treatment for various types of hearing loss and may be indicative of continued expansion in the future.

Cochlear implantation has proven to be a successful (re)habilitative option available to individuals with hearing loss. Recent expansion in eligibility criteria has assisted in making cochlear implantation a viable, successful, and technologically advanced option for an exponentially larger portion of the population (Arnoldner & Lin, 2013). As data have shown, the average life expectancy in the United States has continued to increase with time. One byproduct of this increase is the prevalence of hearing loss, which when left untreated adversely affects safety, communication, and quality of life. Thus, it stands to reason that an increasing number of older individuals may seek treatment via cochlear implantation given the improvement in technology, expanded eligibility criteria, relative safety, and ever-increasing prevalence of hearing loss in this population.

The majority of current literature supports the use of cochlear implantation in the elderly population (Cloutier, Bussieres, Ferron & Cote, 2013; Lachowska, Pastuszka, Glinka & Niemczyk, 2013; Spitzer, Cellum, & Bosworth, 2013; Dillon et al., 2013). One article discusses the importance of elderly patient participation in the pre-implant process and device selection for maximum success. Poor long-term stability of speech recognition was reported in conjunction with poor cognitive test results, leading panelists to unanimously agree on the importance of neuropsychologists' participation in the evaluation process (Backous et al., 2007; Spitzer et al., 2013). In contrast, a study by Dillon et al. (2013) concluded that patients who receive a cochlear implant at age sixty-five or older do not experience a decline in speech perception score with extended listening experience. The same authors also report continued improvements in performance beyond the one-year follow-up point for the same set of individuals. Of course, it is imperative to consider the unique challenges that audiologists face related to cognitive decline, reduced dexterity, and a number of other health issues. Aside from audiologic viability, another important consideration for cochlear implantation in elderly patients is safety. Oftentimes surgeries that are viewed as elective are discouraged in elderly patients for reasons associated with risk. Cloutier and colleagues (2013) reported that cochlear implantation surgery was well-tolerated by patients eighty years of age and older, and found that quality-of-life improvement is comparable to that reported by younger patients. While risk should always be evaluated on an individual basis, the improved quality-of-life and audiologic benefit may outweigh the risks associated with surgery, and age alone should not be an excluding factor for cochlear implantation (Cloutier et al, 2013).

Cognitive decline is not exclusive to the elderly population. Its prevalence, however, is markedly higher as the American population ages. In the most basic sense, the term *cognition* refers to conscious mental activities and includes thinking, understanding, learning, and remembering (Merriam-Webster, 2015). More recently, the relationship between cognition and hearing loss has been a current topic that has generated much interest in the media and research realms. A number of articles very clearly delineate the association between hearing loss and accelerated cognitive decline, incident dementia, and incident cognitive impairment as compared to individuals with normal hearing (Lin et al., 2013; Surprenant & DiDonato, 2014; Gurgel et al., 2014; Lin et al., 2011). While the relationship between amplification and rate of cognitive decline has yet to be solidified, it is plausible to consider that the audiologist plays a role in the care of elderly patients and that the significance of appropriately fit amplification may prove to be an important factor in patient management.

As previously stated, research and census records demonstrate a significant and steady increase in the older population, a population highly infiltrated by hearing loss and cognitive decline. Work by Gantz and colleagues (2006), Arnoldner and Lin (2013), and Gifford and colleagues (2010), substantiate the expanding cochlear implantation criteria expansion and the appropriateness of cochlear implantation as a treatment for hearing loss in older individuals. However, a significant component yet to be revealed relates to potential programming considerations for older cochlear implant users with varying degrees of cognitive function. The effect of cognitive decline on speech understanding is not definitive. Many sources state that long-term speech understanding is maintained, even for individuals with lower or declining cognitive function (Dillon et al., 2013). On the contrary, some research supports deterioration in the ability to understand speech due to memory load, auditory processing, aging and other cognitive processes (Pichora-Fuller, 2003; Humes, 2007). The effect of cognition on speech understanding in older adults certainly warrants further investigation; however, amplification via hearing aids or cochlear implants has been proven to be beneficial regardless.

An essential part of the audiologist's job is maximizing the benefit each eligible patient can receive from his or her cochlear implant. Doing so requires an intricate understanding of the device's functionality and methods by which a device can be manipulated to better serve the patient. Much clinical research has demonstrated the importance of optimizing the cochlear implant processor programming in order to improve adult implant users' speech understanding (Skinner, Holden & Holden, 1997; Skinner et al., 2002; Buechner, Frohne-Buchner, & Gaertner, 2010; Mauger, Dawson, & Hersbach, 2012). One parameter that can be manipulated is stimulation rate. Stimulation rate refers to the rate at which biphasic stimulus pulses are delivered to the electrode array. The numeric value of the rate (i.e. 500 Hz, 1200 Hz) indicates the number of pulses that are delivered to a single electrode contact per second. Stimulation rate has no bearing on *when* the sound is heard, but instead dictates how many "glimpses" of that sound the user receives within a specific time window (Lisa Potts, Hearing Devices III class, February 7, 2014). While it is well-accepted that changes in stimulation rate affect the cochlear implant user's perception of pitch and intensity, the optimal stimulation rate for any given user may starkly contrast that of another audiologically similar patient, due to any number of factors, one of which is nerve integrity.

Various researchers have attempted to define the relationship between stimulation rate and speech perception. Given the effect of stimulation rate on temporal fine structure elements of sound, it would seem reasonable to assume that cochlear implant users utilizing higher stimulation rates would perform better on speech perception tasks. However, several authors refute this notion, reporting that perceptual performance of cochlear implant users is frequently not improved when using a higher rate (Arora, Dowell, & Dawson, 2012; Vandali, Whitford, Plant, & Clark, 2000). Although the results have been variable, stimulation rate likely affects speech understanding, but the quantification and qualification are not yet definitive.

Equipped with this knowledge, scientists and clinical audiologists are working to determine whether any particular set of parameters or map characteristics would assist in maximizing performance for particular subsets of the population. Existing research describes the usefulness of reducing the stimulation rate in pediatric cochlear implant users with auditory neuropathy spectrum disorder (ANSD), a condition affecting neural synchrony (Teagle, 2013; Pelosi et al., 2012). Related to programming but outside of the cochlear implant realm, work by Humes (2008) and Lunner and Sundewall-Thoren (2007) explains that audiologists need to consider cognitive function when programming various parameters during a hearing aid fitting. Lunner and Sundewall-Thoren (2007) specifically address the appropriateness of fast-acting versus slow-acting compression, stating that adults exhibiting age-related cognitive decline perform better with slow-acting compression. Such work demonstrates the utility of knowledge guiding clinical programming protocols and simultaneously highlights the need for similar investigations and development of guidelines as they relate to adult cochlear implant users with varying degrees of cognitive function.

Given what is known about the rate at which the population is aging and seeking hearing healthcare services, the prevalence of cognitive impairment in this population, and the feasibility of cochlear implantation for patients within this group, it becomes increasingly more important that audiologists learn what programming manipulations will lead to optimal performance for any given patient. The current lack of literature attempting to address this issue presents an excellent opportunity to pose questions that will individualize and improve patient care. Thus, the current study seeks to answer the following questions:

1. How much is Mini-Mental State Examination score related to current stimulation rate for adult cochlear implant users?
2. For any given Mini-Mental State Examination score, does stimulation rate affect speech perception abilities?

METHODOLOGY

Materials

The current study utilized an existing database in an attempt to address the above-mentioned research questions. The database was created previous to this study using data from patient files at The Center for Hearing and Balance Disorders in Chesterfield, Missouri. In order to protect all participants included within the database, all private identifiable information was removed, rendering the database de-identified. As such, none of the following information was contained within the database: name, geographical subdivision, date of birth, phone/fax numbers, electronic mail addresses, social security numbers, medical record numbers, health plan numbers, account numbers, biometric identifiers, full-face photographic images, or any other unique identifying numbers. Age was included in the database, with anyone over the age of 89 simply being categorized into an "89+" group per Health Insurance Portability and Accountability Act (HIPAA) regulations. Remaining data points contained within the database include Mini-Mental State Examination score, current stimulation rate, and speech perception score, as determined by the Hearing in Noise Test (HINT) score.

The Mini-Mental State Examination (MMSE) is one of the most commonly used clinical tests for complaints of memory problems. It can be used as part of a battery of tests in diagnosing dementia, and can also be given serially to document the severity or progression of cognitive deficit. This test is given verbally, thus the impact of hearing status must be taken into consideration when evaluating results, particularly for individuals with known hearing loss. Other factors that may influence MMSE score include level of education, native language, and various learning disabilities. The maximum score attainable was 30, which indicated all possible points were earned. A number of contradicting reports of appropriate MMSE score categorization can be found in the literature, making the interpretation of MMSE results dependent upon the source or clinic protocol. The vast majority of sources cite a cut-off score of 24 or 25 to differentiate between normal and abnormal cognitive function. In one case, a score of 27 was used to delineate normal function, however the remainder of the literature does not support the use of this value. Individuals with a score of 27 may perform or function superiorly to an individual that scores a 25, however, both are categorized as having normal cognitive function (Alzheimer's Society, 2012; Folstein, Folstein & McHugh, 1975). The MMSE assesses a number of different cognitive abilities, including memory, attention, and language. Test questions evaluate orientation (e.g. "What is today's date?), registration (e.g. word recall), naming (e.g. pointing to a pen or pencil and requiring the patient to name said object), and reading. MMSE scores in the current study reflect performance when the audiologist administered the test verbally as part of the pre-implant evaluation or periodically throughout the patient's cochlear implant process at regular follow-up appointments.

The Hearing in Noise Test (HINT), developed at House Ear Institute, is used to evaluate an individual's speech recognition abilities in quiet and in noise. Ten, twenty-five sentence lists are available as testing material. The sentences contained within each list were derived from the Bamford-Bench sentences and were normed for naturalness, difficulty, and reliability. HINT sentences approximate a first grade reading level, making them understandable for adults (Nilsson, Soli, & Sullivan, 1994). For the purposes of this study, all HINT scores reflect speech perception performance when sentences were presented in the sound field of a sound booth in the quiet condition. Test sentences were presented at 60 dB SPL using a GSI-61 audiometer.

Participants

The database used for the current study was de-identified, as to eliminate the possibility of participant identification from data included within the database. Inclusion criteria for the current study specified that only individuals over the age of seventy who had been a cochlear implant user for a minimum of three years were to be included for analysis. There were no exclusion criteria within this subset of individuals. A total of 57 database entries, from here forward referred to as "participants", were included for analysis. Participant ages ranged from 70 to at least 89 years of age. However, eighty-nine likely underrepresents age for some participants, as HIPAA qualifications prevent specification of any age over 89 years. For this reason, an accurate average age could not be calculated. Figure 1 depicts a categorical breakdown of participant age, with 6 participants falling in the 70-75 years range, 14 in both the

76-79 years and 80-84 years range, 12 in the 85-88 years range, and 11 in the 89+ years range. Of the 57 participants, 34 were male and 23 were female (Figure 2). All participants contained within the database were implanted with Cochlear Corporation cochlear implant devices and were patients at The Center for Hearing and Balance Disorders.

Study Design/Analysis

Given the nature of the current study, its completion required logical data organization and carrying out of the appropriate statistical analysis. No experimental protocol was implemented.

Correlational studies were completed to allow for analysis of relationships between each of the variables of interest. Using Statistical Package for the Social Sciences (SPSS) software, bivariate correlational analyses were completed for participant age, current stimulation rate, HINT score, and MMSE score. Figures 6, 7, 8, 9, 10, and 11 depict the corresponding scatterplot for each correlation. A correlation matrix was also constructed as a method of quantifying inter-variable relationships. Completion of the correlation matrix also enabled the researcher to determine whether age uniquely interacted with each of the remaining variables, to then conclude whether further analysis was necessary. Pearson correlation coefficients were calculated for each set of variables and significance was determined at the $p < 0.05$ or $p < .01$ level, as specified by asterisks. Partial correlation analyses were completed and served to evaluate the relationship among variables when participant age was statistically controlled. Following completion of all correlational studies, regression analyses were completed to further quantify the interaction between study variables.

Ethical Considerations

The Institutional Review Board (IRB) at Washington University School of Medicine reviewed the design, materials, and various other parameters of the current study. Upon doing so, it was determined that because a secondary data set was utilized, no original patient interaction took place and no private identifiable information was contained within the database. As such, no potential risk to human participants existed, thus the study did not meet criteria for IRB oversight.

RESULTS

The participants had a mean age of 82.02 (SD = 5.25) and mean MMSE score of 26.98 (SD = 3.22). The median stimulation rate was 900 Hz and the mean HINT score was 80.5% (SD = 18.5). The minimum MMSE score was 12, while ten participants had a score of 30. All descriptive statistics are contained within Table 1. Histograms representing the distribution of stimulation rates, MMSE scores, and HINT scores across the study participants are shown in Figures 3-5.

Correlational Analyses

Figures 6-11 present the scatterplots for each of the study variables plotted individually as compared to each of the other study variables. A Pearson correlation coefficient was computed to assess the relationship between MMSE score and current stimulation rate. There was a positive correlation between the two variables ($R = .284$, $n = 57$, $p = .032$) at the $p < 0.05$ significance level. Figure 6 illustrates this relationship. Increases in MMSE score were correlated with higher stimulation rates. In order to investigate the relationships between other study variables and determine the necessity of controlled analyses, a correlation matrix was assembled (Table 2). The specific function of this correlation matrix was to confirm whether age was significantly correlated with each study variable and determine the need for further statistical analyses controlling for age. This analysis also served to supplement interpretation of the variable relationships. The correlation matrix revealed a significant positive correlation between MMSE score and HINT score ($R = .426$, $n = 57$, $p = .001$). Thus, a higher MMSE score is significantly correlated with a higher HINT score (Figure 7). Correlational analyses also confirmed the negative relationship between MMSE score and participant age ($R = -.413$, $n = 57$, $p = .001$). This correlation indicated that increased participant age is associated with decreased MMSE score (Figure 8). Correlations between HINT score and participant age, stimulation rate and participant age, and stimulation rate and HINT score were all insignificant. These relationships are shown in Figures 9, 10, and 11, respectively.

Due to the significant correlation between MMSE score and age, partial correlation analyses were performed to examine the relationship between the study variables when age was statistically controlled. Partial correlation results revealed a significant correlation between both MMSE and stimulation rate ($R = .281$, $n = 57$, $p = .036$), and MMSE and HINT score ($R = .430$, $n = 57$, $p = .001$), even after controlling for age. While there was a very slight decrease, the stability of the significance value from the partial correlation analysis as compared to the simple correlation indicates that only a minimal amount of the relationship between MMSE score and stimulation rate is due to the influence of age. The age-controlled significance value supporting the positive correlation between MMSE and stimulation rate is shown in Table 3. The corresponding scatterplot is depicted in Figure 12. Partial correlation significance results for the MMSE score and HINT score indicated that age was not largely responsible for the correlation between the two variables. The relationship between MMSE score and HINT remains significant when age is partialled out, supporting that MMSE score and HINT score are positively correlated (Table 4), less the influence of age. This relationship is illustrated in Figure 13. Results from the age-controlled partial correlation calculations confirmed the validity of the correlations between MMSE score, stimulation rate, and HINT score.

Interaction of MMSE score, rate, and speech perception score

Regression analysis indicated that 17% of the variability in MMSE score is due to age ($R = .413$, $R^2 = .170$, $p = .001$), which was statistically significant at the $p < .01$ level. However, age was not a statistically significant predictor of stimulation rate ($R = .070$, $R^2 = .005$, $p = .605$) or HINT score ($R = .087$, $R^2 = .008$, $p = .520$). Multiple regression analysis was used to develop a model for predicting HINT scores from MMSE scores and stimulation rates. Basic regression coefficients and general statistics about the model are shown in Table 5. The predictor model was able to account for approximately 21% of the variability in speech perception score, as evidenced by the HINT score. Prior to completion of the regression analysis, an analysis of variance (ANOVA) was computed to ensure the variable means were significantly different before proceeding. F-test results confirmed that the variable means were significantly different ($F(3,53) = 5.810$, $p = .002$). While the interaction between MMSE score and stimulation rate did not have a significant effect on expected speech perception score ($\beta = -.055$, $p = .720$), both MMSE score ($\beta = .471$, $p = .003$) and stimulation rate ($\beta = -.275$, $p = .037$) were significant, independent predictors of speech perception score after controlling for the other variables in the model.

DISCUSSION

Results of the current study suggest that while users with higher MMSE scores tend to use higher rates and score higher on a speech perception task, simple correlation indicated that stimulation rate was not correlated with speech perception abilities. This finding is consistent with the findings of Arora et al. (2012) and Vandali et al. (2000), which both discredited any significant effect of increased rate on better speech understanding. However, the subjective reports of improved performance noted within the article by Vandali and colleagues (2000), may be consistent with the finding from the current study that stimulation rate becomes a significant independent predictor of HINT score when all other study variables are controlled. The partial correlations were calculated in order to control for age. Logic indicates that age would interact significantly with each of the study variables, given what we know about the innumerable effects of aging. Thus, in an effort to be more thorough and accurate, age was statistically controlled by the researcher to truly assess whether any one of the variables provided a significant correlation. Even with age partialled out, stimulation rate and speech perception score were significantly correlated with MMSE score, signifying the important role a measure like the MMSE may play in providing information about an appropriate stimulation rate or an expected speech perception outcome.

Results from the multiple regression analysis point to the significant percentage of the variability in speech perception score that can be attributed to both MMSE score and stimulation rate. This result highlights the value of having both sets of information in predicting how well adult patients will perform with cochlear implants and the potential utility of incorporating regular MMSE evaluations as part of the clinical protocol. That said, the interaction between MMSE and stimulation rate did not predict the speech perception score. In other words, the relationship between MMSE score and speech perception ability does not change at different levels of stimulation rate. While further studies involving similar data would be extremely useful, this particular piece of data indicates that individuals with lower MMSE scores, indicating poorer cognitive function, may not perform better with a rate that is different from cochlear implant users with higher MMSE scores.

Clinical Ramifications

Implications for clinical practice are many, but the tendency for patient individuality affecting preference is noteworthy and realistic. Clinical audiologists, particularly for older adult cochlear implant users, will see the same patients periodically and at specific intervals. Because of this regularity, audiologists serve an important role in the observation and tracking of cognitive functioning. While audiologists and hearing healthcare specialists see cognition in the context of audition, cognitive functioning affects every facet of an individual's life. It is important to recognize that a decline in cognition may be evidenced by a decrease in score on speech perception tests. While the results of the current study do not support the indication that decreasing the stimulation rate for someone with low cognitive function leads to better speech perception outcomes, it is of note that participants in this study with lower MMSE scores did tend to use a slower stimulation rate. Given that, and the fact that MMSE and stimulation were both independent predictors of HINT scores, a significant change in speech perception ability may necessitate re-testing with the MMSE to detect any cognitive changes or a trial with lower stimulation rates to see whether any change makes a significant difference.

The findings contained within this study suggest some benefit may result from assessing current cochlear implant programming protocols at clinics across the country. While a neuropsychological examination or screening may already be part of many centers' protocol, the value of such information has proven to be valuable, and serial testing utilizing a cognitive evaluation like the MMSE would allow for monitoring. In addition, the protocol delineating trials with stimulation rates may be deserving of further consideration. The positive correlation between MMSE and stimulation rate leads one to question whether an older patient with lower cognitive function would benefit from a slower rate than he or she is currently using. While the lack of interaction between the two variables as they pertain to speech perception outcomes in this study may lead someone to believe the answer is no, the significance of each variable as an individual predictor warrants further investigation.

Many current protocols describe an initial stimulation process that leads the new user through a trial period with a variety of stimulation rates. Each week the patient has the opportunity to trial a new set of map parameters, generally presented in a progressive fashion. Oftentimes the preferred map from the previous week is maintained on the processor, serving as a reference point and a back up in case of poor sound quality with the newest maps. Once the patient has trialed a number of different maps and experimented with a variety of stimulation rates, the clinician and patient work together to determine the set of parameters that reflects adequate sound quality, patient preference, and leads to optimal performance. However, in the majority of cases, regardless of prospective changes in cognitive function, a cochlear implant user does not revisit this process. Results from this study suggest that doing just that may be beneficial for the patient, and be a means of providing a more real-time, situationally-specific reflection of preference. Without re-trialing various stimulation rates, how can clinicians be certain that what a patient preferred at the age of 70 with intact cognition accurately reflects what he or she may prefer at age 80 following a declination in cognitive function?

An additional consideration stemming from the results of the current study is the apparent lack of neuropsychological evaluations appropriate for the deaf and hard of hearing population. Similar to the MMSE, many tests of cognitive function are given verbally, requiring audition and auditory processing skills in addition to intact cognition to score well on the test. Many individuals with hearing impairment, particular cochlear implant candidates being assessed as part of the pre-implant evaluation process, have severe to profound hearing loss. This fact makes it difficult to tease out whether the corresponding MMSE score is a true reflection of cognitive function, or is influenced by the presence of hearing loss.

In addition to potential implications for cochlear implant center protocols, the results from the current study encourage considerations for programming adult cochlear implant users' device(s). As previously mentioned, research by Teagle (2013), Pelosi et al. (2012), Humes (2008) and Lunner and Sundewall-Thoren (2007) describes the utility of programming manipulations to provide users with a signal that is most beneficial, based upon various conditions. Lunner and Sundewall-Thoren (2007) describe the use of slow-acting versus fast-acting compression in hearing aids for older adults, citing better performance for adults with declining cognitive function utilizing slow-acting compression. Similarly, Teagle (2013) suggests considering slower stimulation rates for pediatric cochlear implant users with ANSD, as to allow for optimal, synchronous neural firing. With these, and several other research findings translating into specific strategies or guidelines for programming devices for individuals that fall into said populations, the utility of understanding what mapping parameters may be manipulated in order to optimize performance for the older population with cognitive decline becomes glaring. The feasibility and appropriateness of cochlear implantation as a treatment for hearing loss in this population is well-established and the number of individuals entering the older sector of the population with hearing loss is ever-increasing. Individuals with lower MMSE scores tend to score more poorly on speech perception tests. MMSE score and stimulation rate are both independent predictors of performance outcome, indicating the necessity of further exploration into how these factors interact with each other to affect a user's ability to understand speech. These facts support the need for further research that aims to maximize benefit experienced by elderly adult cochlear implant users by investigating what adjustments or changes can be made by clinicians to affect real-world outcomes.

Limitations

The nature of this study lends itself, unfortunately, to a number of limitations. First, the impact of hearing loss on MMSE score validity must be noted. The MMSE is administered verbally, making it easy to imagine how hearing loss may prohibit a patient from earning a score that is a true reflection of cognitive ability. Other confounding factors include native language, learning disability, speech difficulties, and educational background. Future studies should consider other cognitive assessments that may reduce the influence of hearing sensitivity. Researchers within the area of cochlear implants will attest to the difficulty associated with controlling for the seemingly endless number of individual variables that affect performance for cochlear implant users. Some of these variables include age at implantation, use of amplification prior to implantation, pre- vs. post-lingual deafness, map parameters, surgical factors, and personal motivation, among many others, for which there was much variability within the current study's sample. The current study did not control for several of the aforementioned variables, which presents a clear limitation. In addition, stimulation rate in the current study does reflect the patient's preference immediately post-initial stimulation. However, typical cochlear implant center protocols do not require subsequent trialing of other stimulations to see whether stimulation rate preference is maintained, or changes as a function of another variable. Thus, the current study cannot determine whether any trends in stimulation rate based upon MMSE score or age were a reflection of current preference, or simply the initial preference.

Future Research

The importance of understanding the affect of particular mapping parameters for adult cochlear implant users with varying degrees of cognitive function is one that will not fade with time, but instead become increasingly more crucial over the next several years. Future research concerning this topic should be conducted with a larger number of participants representing a wide range of cognitive function. One issue that is often cumbersome in cochlear implant research is the difficulty or inability to control for the high amount of individual variability. The current study was no exception to that challenge and it would behoove future research in this area to control for as much variability as possible. Speech perception performance could be directly evaluated by scoring speech perception with lower stimulation rates versus higher stimulation rates for the same individuals within a group of interest. In this case, the performance of individuals with lower cognitive function could be targeted specifically. Lastly, exploration of other cochlear implant mapping parameters, including processing and pre-processing strategies, may prove to be foundational in developing a strong knowledge base and clinical guideline to assist audiologists in optimal, individualized programming of cochlear implants in the older adult population.

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TABLE 1

Descriptive Statistics

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Mini-Mental State Examination Score	57	18	12	30	26.98	3.215
Current CI Stimulation Rate	57	1550	250	1800	935.09	383.588
HINT Score	57	76	24	100	80.46	18.569
Participant Age	57	18	71	89	82.02	5.249
Valid N (listwise)	57					

Table 1. Descriptive statistics for each study variable are displayed in the table above.

TABLE 2

Correlations					
		MMSE Score	Stimulation Rate	HINT Score	Participant Age
MMSE Score	Pearson Correlation	1			
	Sig. (2-tailed)				
	N	57			
Stimulation Rate	Pearson Correlation	.284*	1		
	Sig. (2-tailed)	.032			
	N	57	57		
HINT Score	Pearson Correlation	.426**	-.121	1	
	Sig. (2-tailed)	.001	.369		
	N	57	57	57	
Participant Age	Pearson Correlation	-.413**	-.070	-.087	1
	Sig. (2-tailed)	.001	.605	.520	
	N	57	57	57	57

*. Correlation is significant at the 0.05 level (2-tailed)
**. Correlation is significant at the 0.01 level (2-tailed)

Table 2. Correlation matrix constructed to quantify the relationship of each of the study variables with each other. Values on the diagonal represent the relationship of each variable with itself, thus the value of 1. Values above the diagonal are exact replications of values below the diagonal; therefore boxes above were left blank.

TABLE 3

Partial Correlation					
Control Variables			MMSE Score	Stimulation Rate	Participant Age
Participant Age	MMSE Score	Correlation	1.000		
		Sig. (2-tailed)			
		df	0		
	Stimulation Rate	Correlation	.281*	1.000	
		Sig. (2-tailed)	.036		
		df	54	0	

*. Correlation is significant at the 0.05 level (2-tailed)

Table 3. Partial correlation calculation to investigate the relationship between MMSE score and current stimulation rate while participant age was statistically controlled.

TABLE 4

Partial Correlation					
Control Variables			MMSE Score	HINT Score	Participant Age
Participant Age	MMSE Score	Correlation	1.000		
		Sig. (2-tailed)			
		df	0		
	HINT Score	Correlation	.430	1.000	
		Sig. (2-tailed)	.001		
		df	54	0	

Table 4. Partial correlation calculation to investigate the relationship between MMSE score and HINT score while participant age was statistically controlled.

TABLE 5

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.497[a]	.247	.205	16.558

a. Predictors: (Constant), MMSE Score, Stimulation Rate, MMSE_Stimulation Rate Interaction

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	80.679	2.278		35.412	.000
	MMSE Score	2.722	.863	.471	3.155	.003**
	Stimulation Rate	-.013	.006	-.275	-2.144	.037*
	MMSE_Stimulation Rate Interaction	-.001	.002	-.055	-.361	.720

a. Dependent variable: HINT Score
** $p < .01$
* $p < .05$

Table 5. Model summary and coefficients table for regression analysis.

FIGURE 1

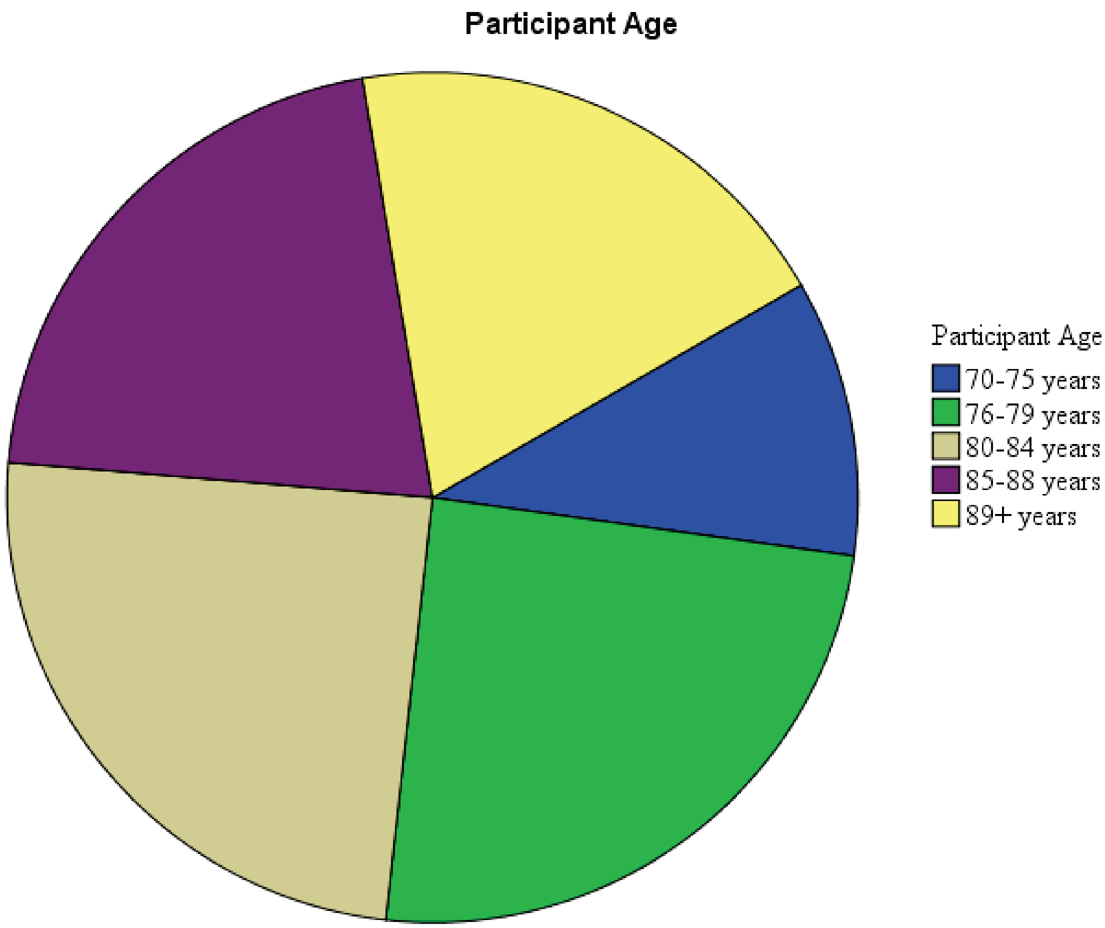

Figure 1. Graphical representation of participant age categorized into five groups, as defined in the key shown above.

FIGURE 2

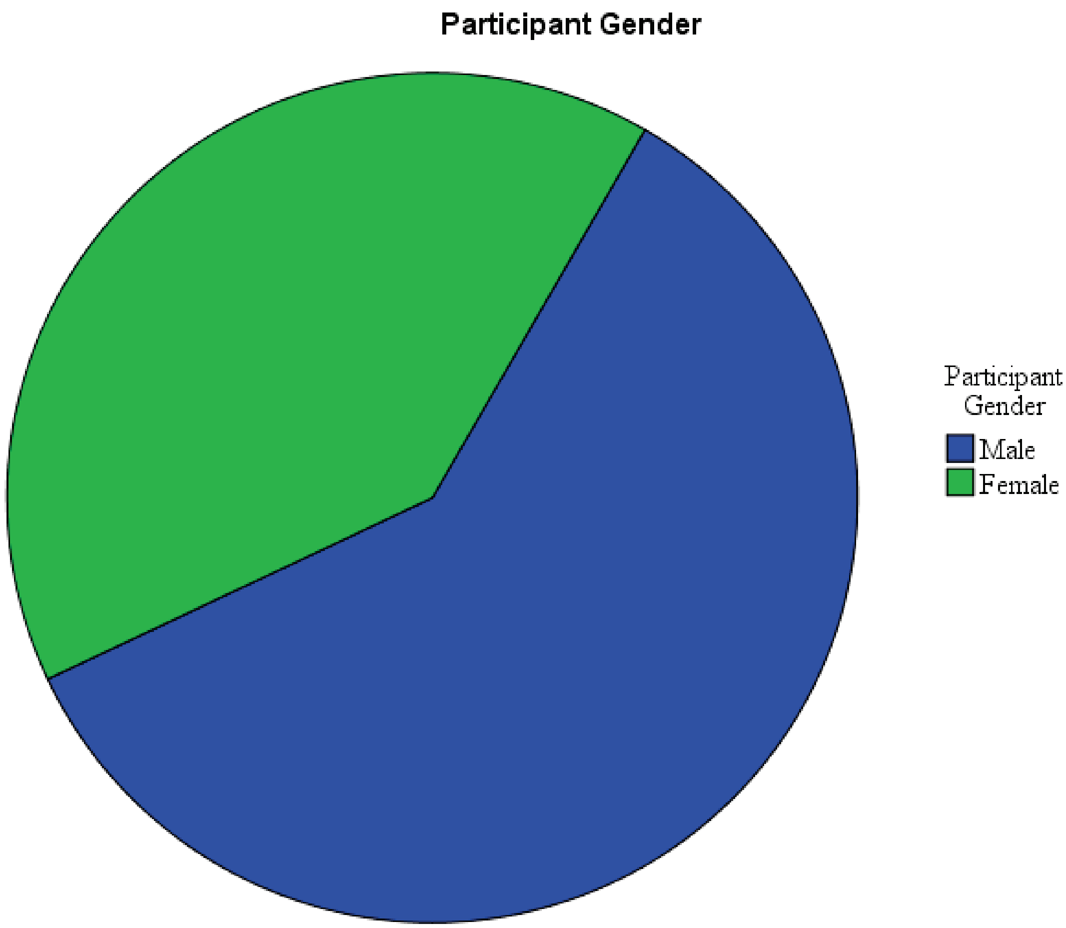

Figure 2. Graphical representation of participant gender. Key is shown above.

FIGURE 3

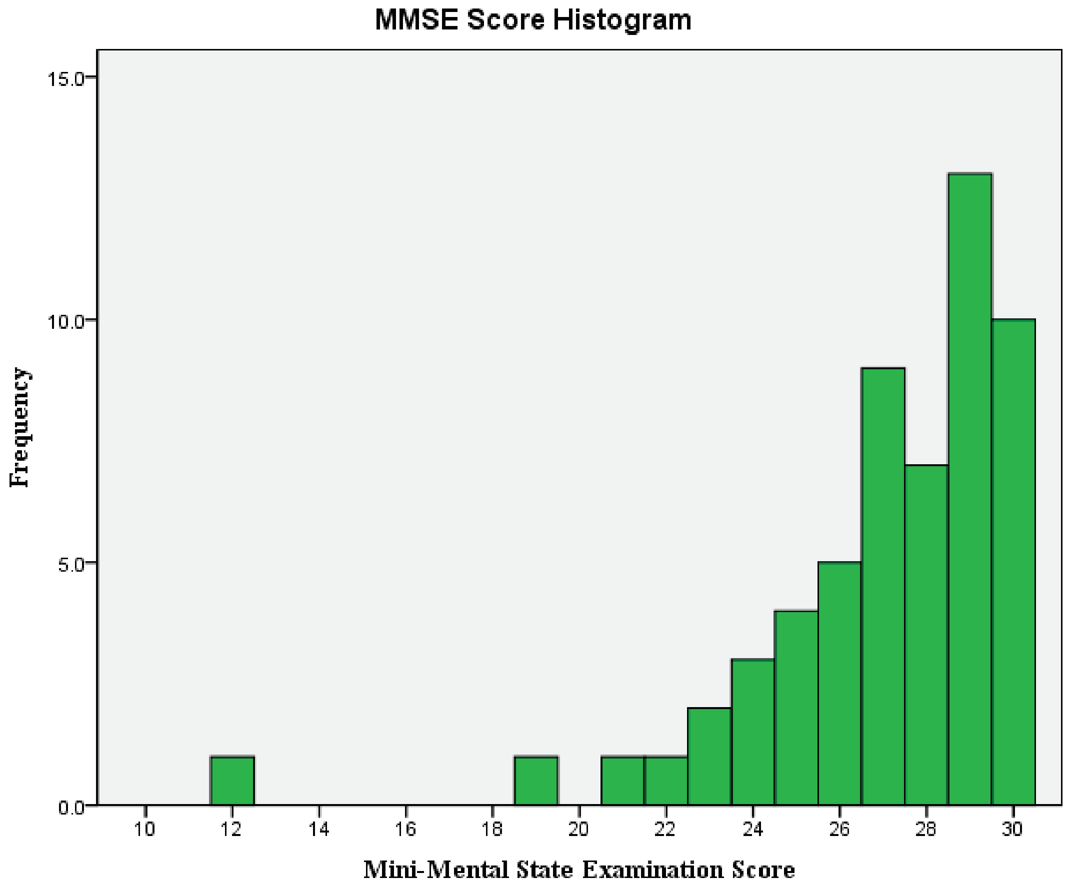

Figure 3. Histogram demonstrating the distribution of Mini-Mental State Examination scores across all study participants. An MMSE score of 30 represents the highest score attainable.

FIGURE 4

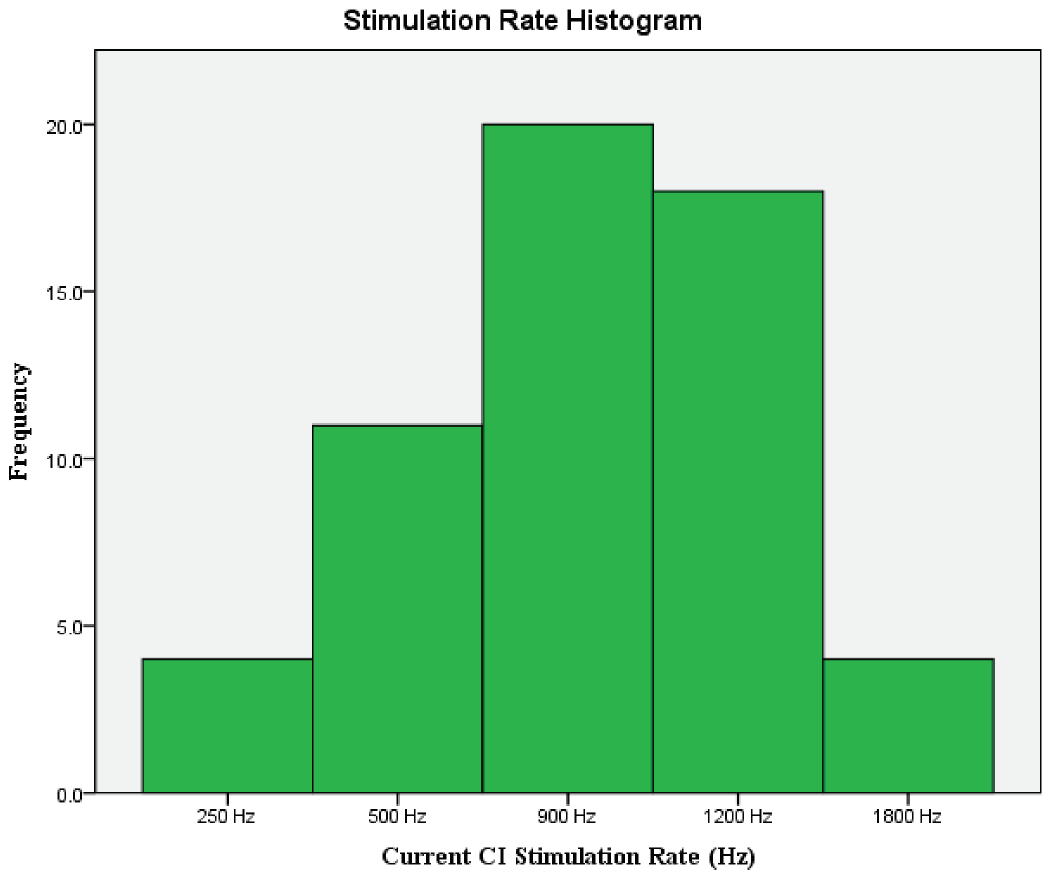

Figure 4. Histogram demonstrating the distribution of current stimulation rates used by all study participants. Stimulation rates from 250 Hz to 1800 Hz are represented above.

FIGURE 5

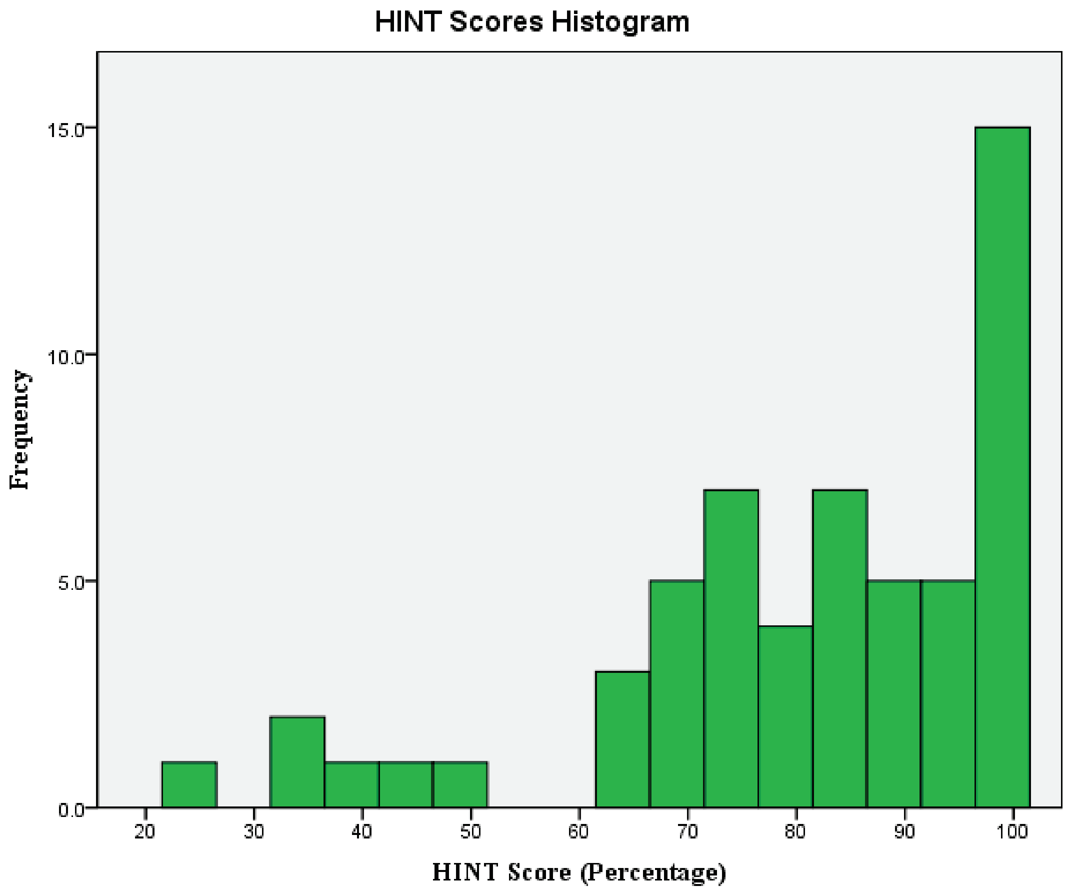

Figure 5. Histogram demonstrating the distribution of Hearing in Noise Test scores across all study participants. 100% represents the highest score achievable.

FIGURE 6

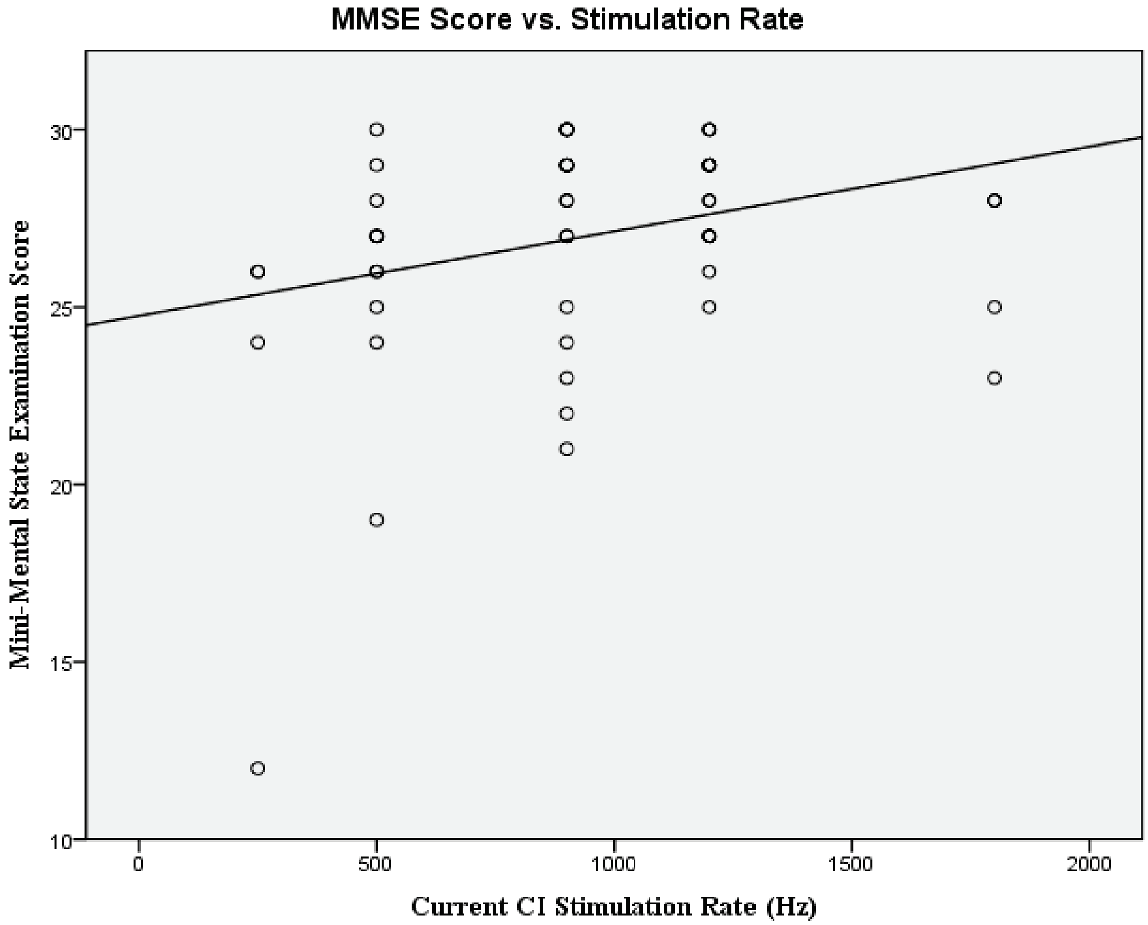

Figure 6. Scatterplot illustrating the relationship between MMSE score and current stimulation rate across all study participants. Significant positive correlation is demonstrated above.

FIGURE 7

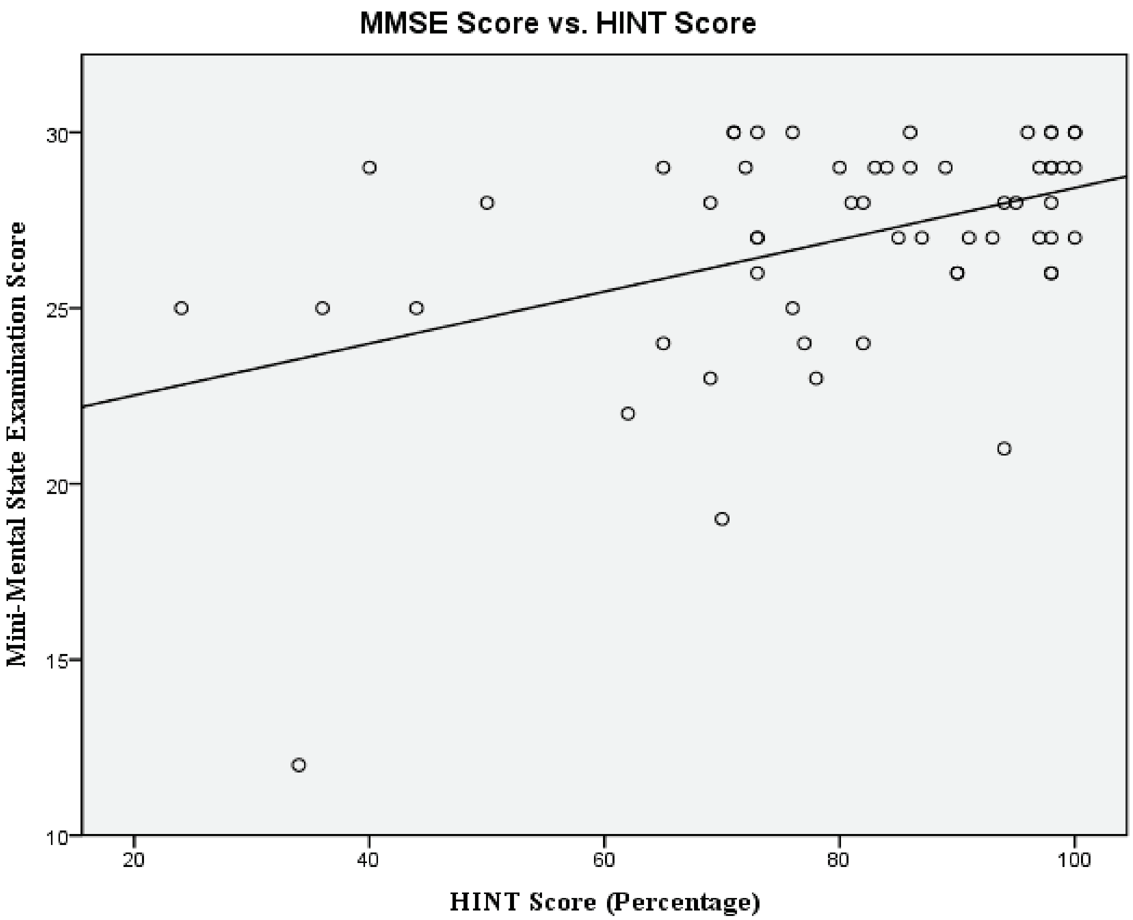

Figure 7. Scatterplot illustrating the relationship between MMSE score and HINT score across all study participants. Significant positive correlation is demonstrated above.

FIGURE 8

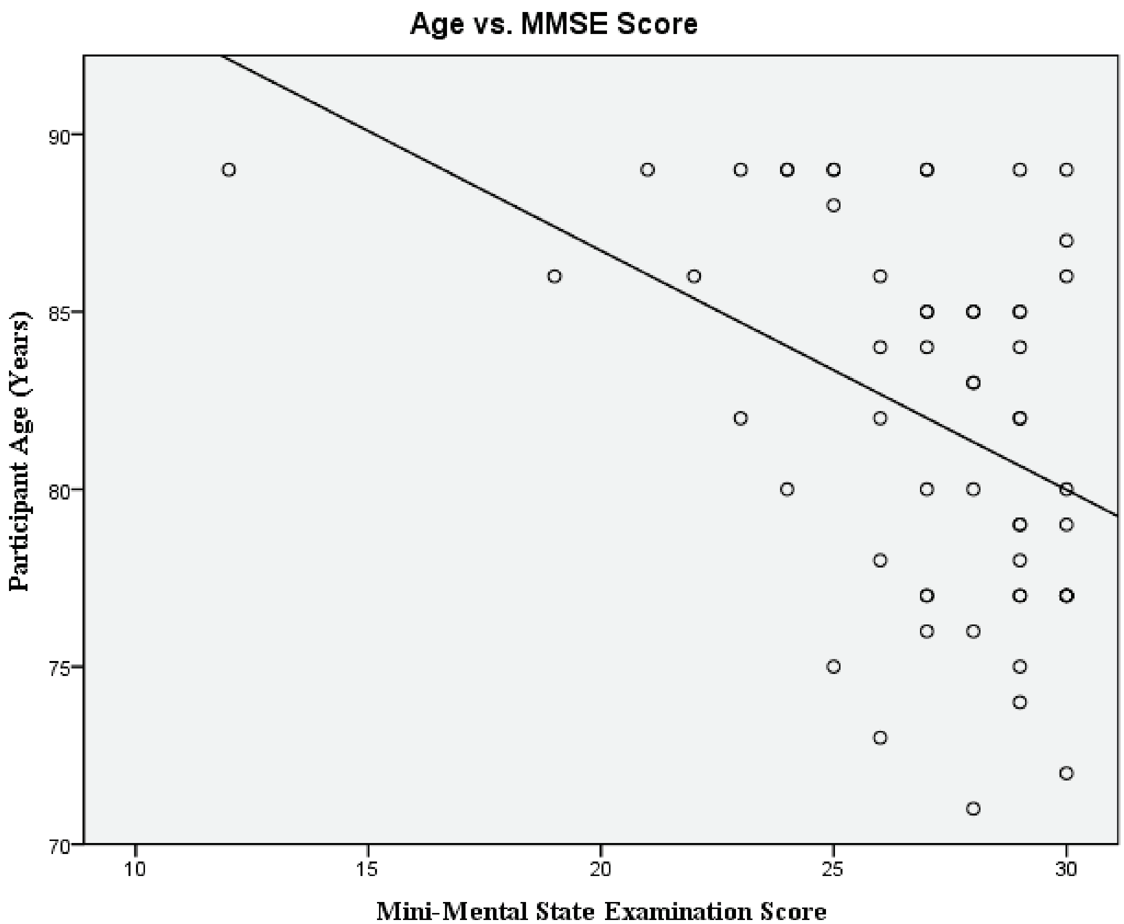

Figure 8. Scatterplot illustrating the relationship between MMSE score and participant age for all participants. Significant negative correlation is demonstrated above.

FIGURE 9

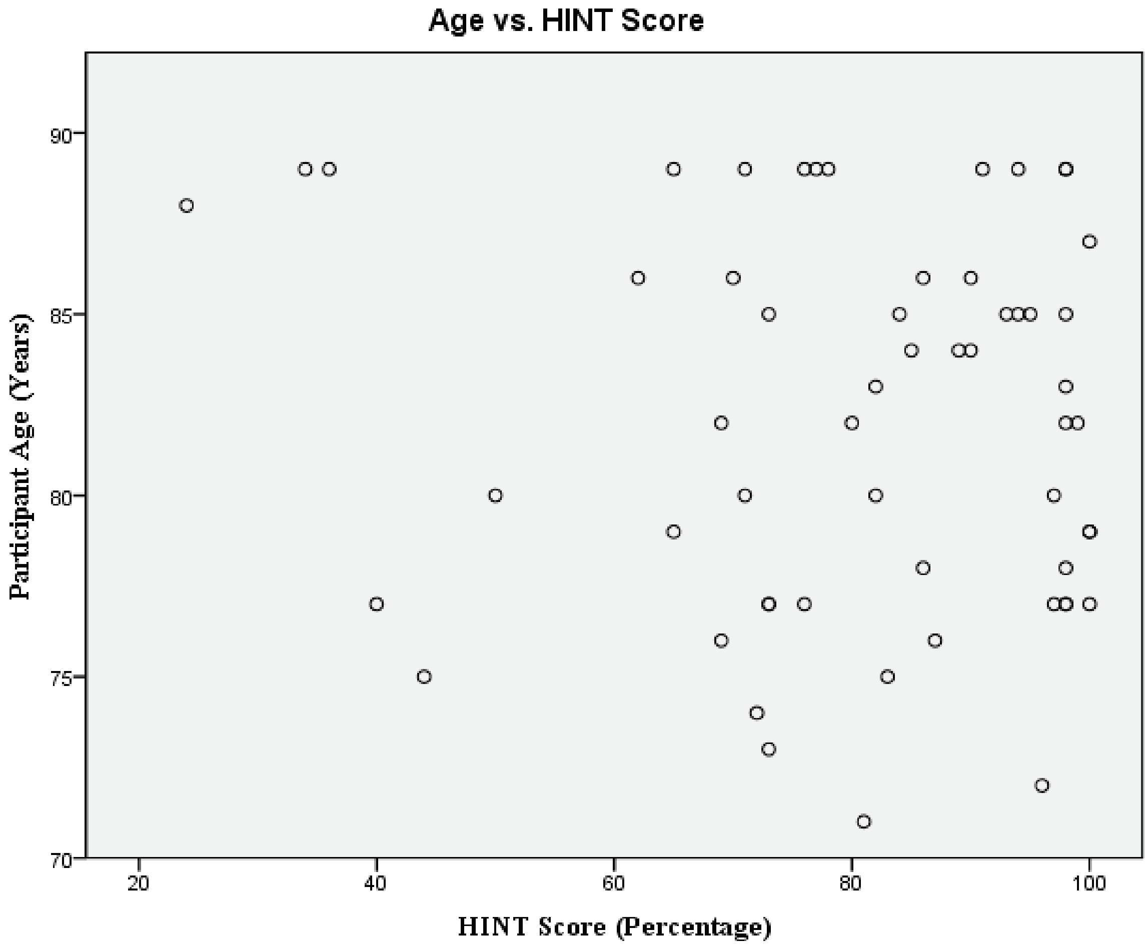

Figure 9. Scatterplot illustrating the correlation between participant age and HINT score for all study participants. The scatterplot above confirms no significant relationship between the two variables.

FIGURE 10

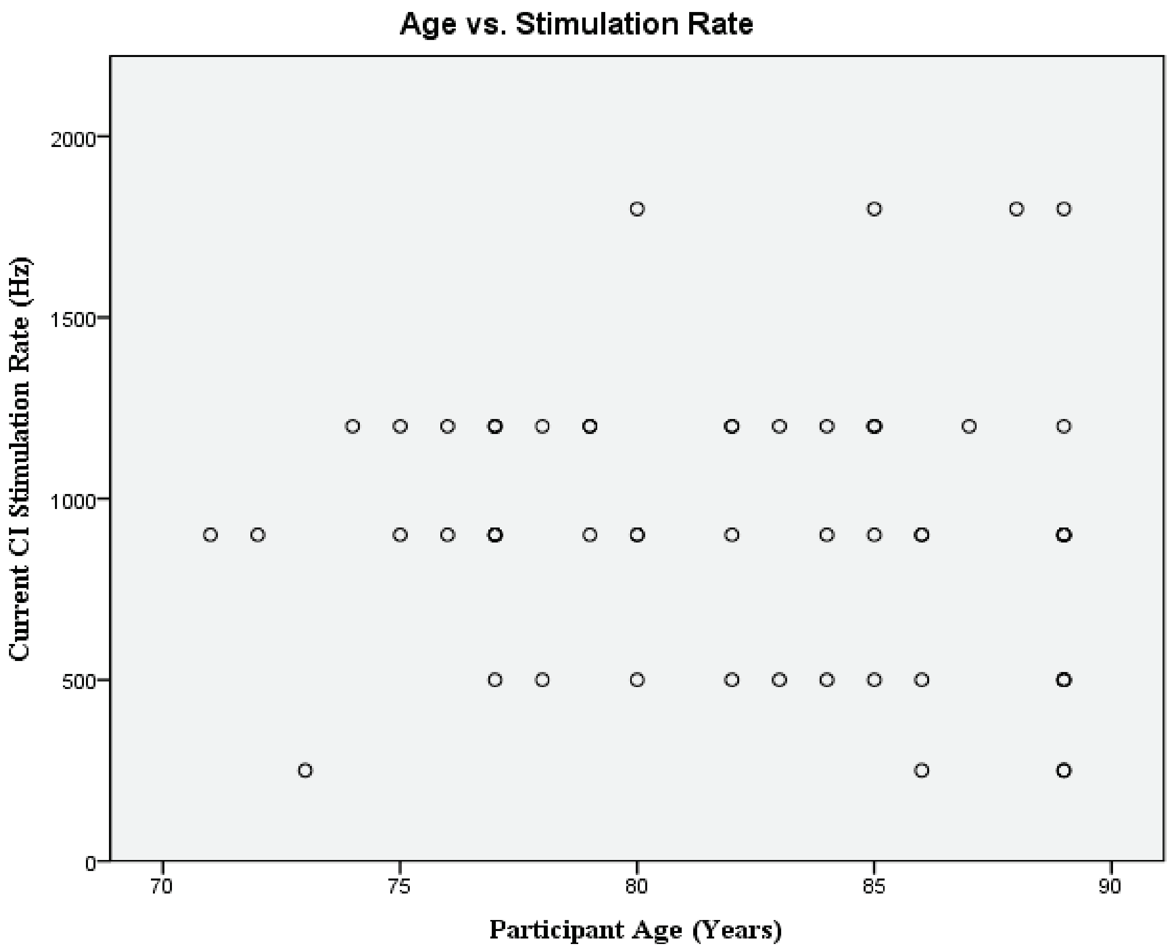

Figure 10. Scatterplot illustrating the correlation between participant age and current stimulation rate for all study participants. The scatterplot above confirms no significant relationship between the two variables.

FIGURE 11

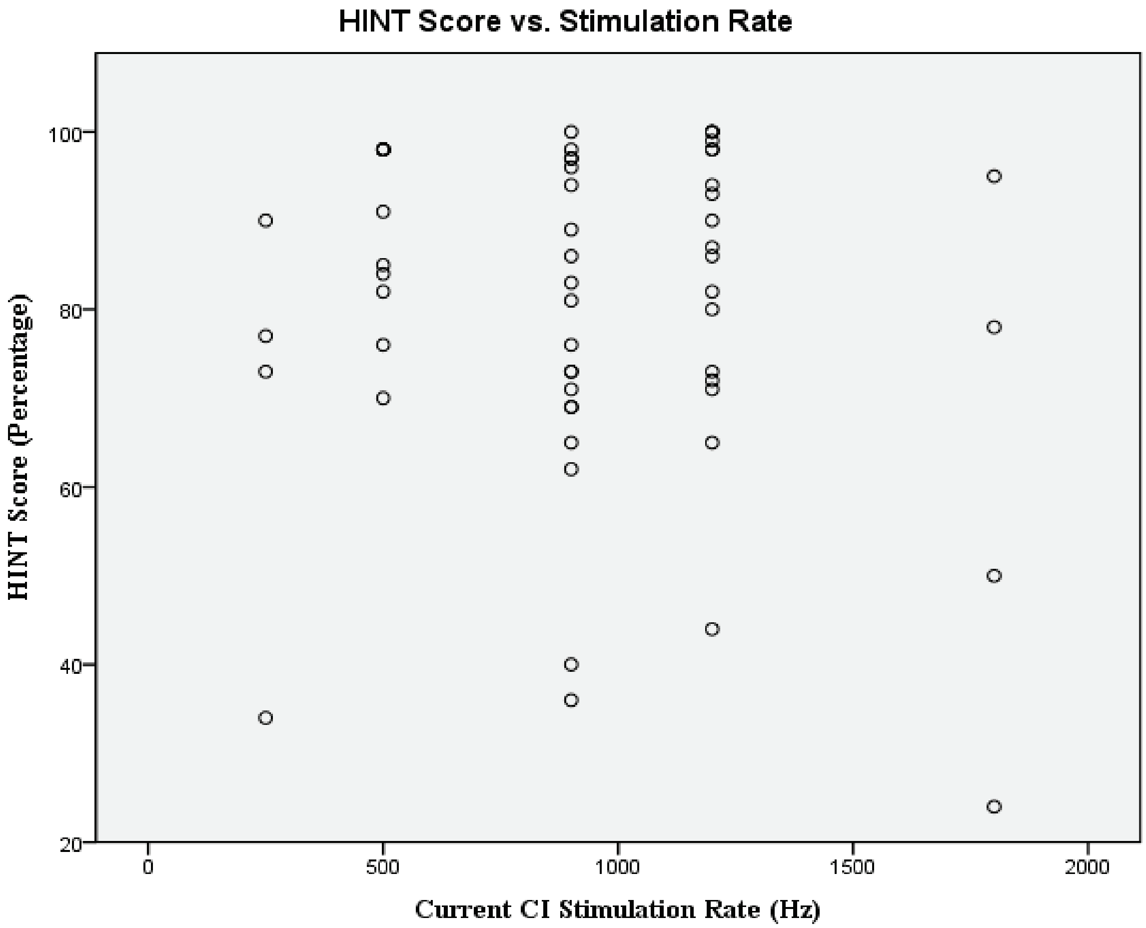

Figure 11. Scatterplot illustrating the correlation between HINT score and current stimulation rate for all study participants. The scatterplot above confirms no significant relationship between the two variables.

FIGURE 12

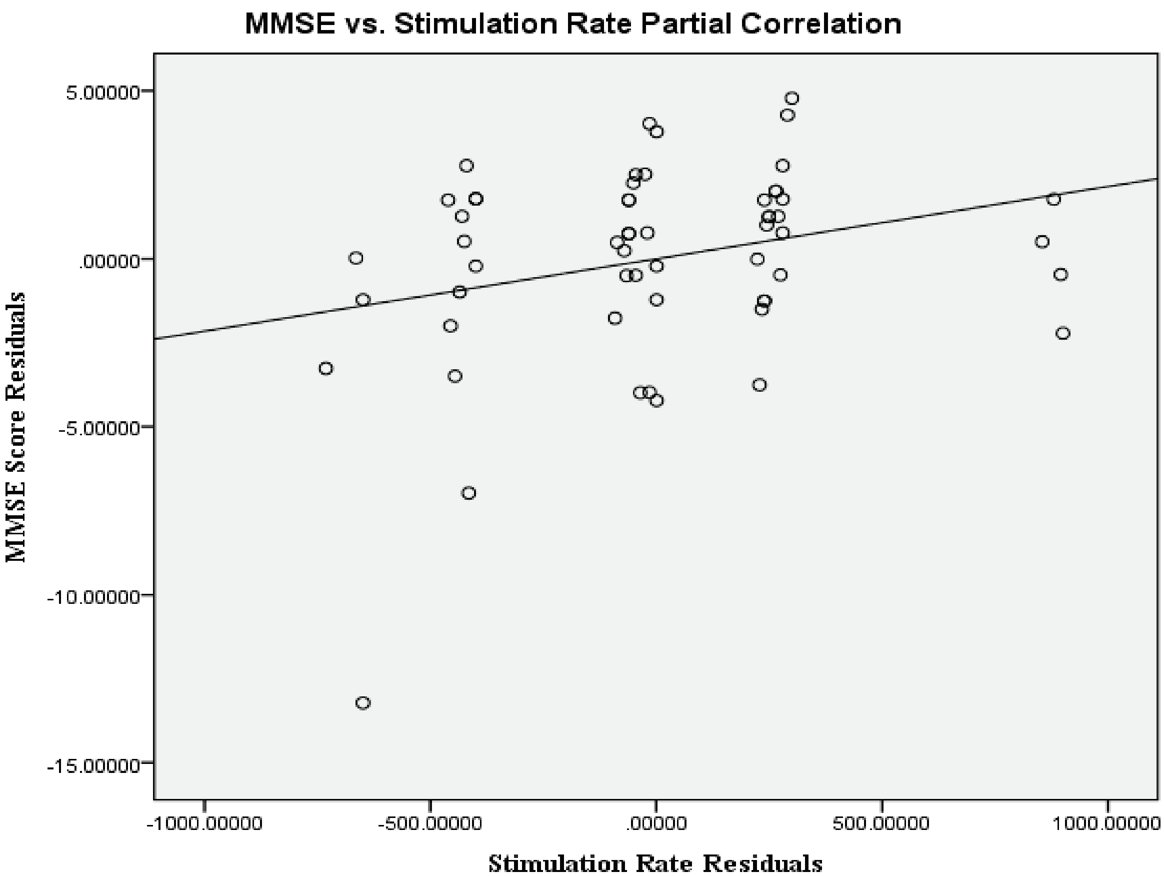

Figure 12. Scatterplot illustrating the partial correlation between MMSE score and current stimulation rate for all study participants. Partial correlation analyses compute the relationship between the variables of interest while controlling for participant age. Results of this partial correlation are illustrated above.

FIGURE 13

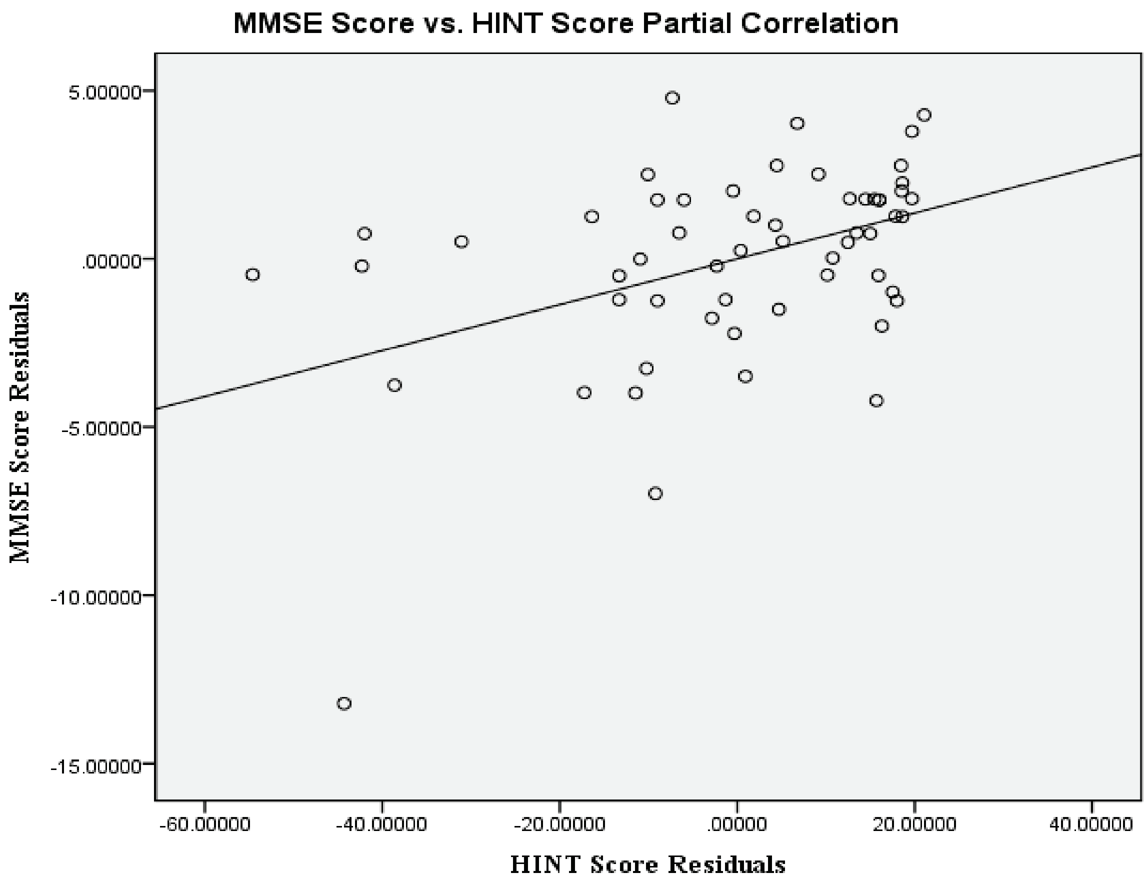

Figure 13. Scatterplot illustrating the partial correlation between MMSE score and HINT score for all study participants. Partial correlation analyses compute the relationship between the variables of interest while controlling for participant age. Results of this partial correlation are illustrated above.